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# حلول امتحانات Energy

## Sample Questions :
## Energy Conservation

① Explain what is meant by each of the following:

- Fuel Cell
- Photovoltaic Cell.
- The 3 T's of combustion
- Energy gap $E_g$ of a semiconductor
- Cell overpotential.
- Thermal efficiency of a fuel cell
- Calorific value of a fuel.
- Steam turbine.

② Explain why:

- Fuel cells have a higher thermal efficiency than a traditional power generation system.
- Alkaline fuel cells cannot be used with a carbonaceous fuel
- Carbon monoxide is not suitable for low temperature fuel cells but can be used for high temperature fuel cells
- Fuel cells are still expensive methods for power generation.
- Carbon dioxide is recycled from anode to cathode in molten carbonate fuel cells.
- The thermal efficiency of a traditional power plant does not exceed 40%.
- The efficiency of a photovoltaic cell does not exceed 12%.
- There is current research for the development of a semiconductor with energy gap $E_g$ around 1.1 eV

(3) What are the advantages and disadvantages of a fuel cell as power generation devices?

(4) What are the types of fuel cells? What is the normal operating temperature and type of electrolyte used in each?

(5) Write down the electrode reactions for each of the following cells.

- Alkaline fuel cell with $H_2$ as a fuel.
- Molten carbonate fuel cell with CO as a fuel.

(6) A fuel cell operating at a current density of 6 kA/$m^2$ and a potential of 1 V. What is the needed electrode area for a power generation of 1 KW?

(7) A fuel cell with cell reaction with $(-\Delta G) = 57$ kcal/mole, $n = 2$. What is the equilibrium potential and what is the actual potential if the cathode overpotential, anode over-potential and IR drops are 300, 400 and 100 mV, respectively?

(8) What is the theoretical efficiency for a boiler with $T_2 = 600°C$, $T_1 = 25°C$?

CAIRO UNIVERSITY

CHEMICAL ENGINEERING DEPARTMENT

Final Exam in

Selective Course (: Energy Conservation)

May 2007

Total Marks : 35

Time Allowed = 2 hr

Attempt all questions :

① Explain each of the following:

a) Fuel cells have a higher thermal efficiency than a traditional power generation system.

b) Alkaline fuel cells cannot be used with a carbonace fuel.

c) Carbon monoxide is not suitable for low temperatu fuel cells but is used as a fuel for high temperature fuel cells.

d) Carbon dioxide is recycled from ~~ext~~ anode to cathode in molten carbonate fuel cells when a carbonaceous fuel is used.

e) The overall efficiency of a photovoltaic cell is still less than 12 %. equivalent to max. wave length solar radiation photons

(10 Marks

② Draw a schematic diagram of a fuel cell stac showing the main components and the method of electric connection. What are the known types of fuel cells and what are the normal operating temperatures and used electrolyte for each

(10 Mark

$6H^+ + \frac{3}{2}O_2 + 6e^- \longrightarrow 3H_2O$

$CH_3OH + \frac{3}{2}O_2 \rightarrow CO_2 + 2H_2O$

③ A $H_2/O_2$ fuel cell operating at a temperature of 60 °C at which $\Delta G$ of the water formation reaction is $-57$ kcal/gmole. What is the equilibrium potential at these conditions? If the cathode overpotential, anode overpotential and $iR$ drop at these conditions and at a current density of 6 $kA/m^2$ are 200, 300 and 100 mV, respectively; what will be the actual potential and power density at these conditions?

$2CH_3OH + 3O_2 \rightarrow 2CO_2 + 4H_2O$

(10 Marks)

④ Write down the electrode reactions of:

a) a methanol / air fuel cell with phosphoric acid electrolyte

$CH_3OH + H_2O \rightarrow CO_2 \; 2e^-$

$H^+ \; e^- \rightarrow H_2O$

b) a carbon monoxide / air fuel cell with molten carbonate electrolyte.

$H_2 \rightarrow 2H^+ + 2e^-$

$2H^+ + \frac{1}{2}O_2 + 2e^- \rightarrow H_2O$

$H_2 + \frac{1}{2}O_2 \rightarrow H_2O$

(5 Marks)

$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

$H_2O + \frac{1}{2}O_2 + 2e^- \rightarrow 2OH^-$

$\int_{E_g}^{\infty} N_E E \, dE$

$\int_0^{\infty} N_E E \, dE$

$H_2 + OH^- \rightarrow H_2O$

$2CH_3OH + 3O_2 \rightarrow 2CO_2 +$

$CH_3OH + H^+ \rightarrow$

$V = \frac{\text{open circuit volt}}{\text{Energy gap}}$

current $= \frac{\text{flux of electrons at short circuit}}{\text{flux of ...}}$

fill factor $= \frac{\text{current} \times \text{pot.}}{\text{current @ short circuit} \times \text{open circuit volt}}$

* Fuel cells
are electrochemical devices that converts chemical energy of a reaction directly into electric energy.
In a typical fuel cells gaseous fuels are fed continuously to the anode ~~and~~ [usually $H_2$] and oxidant [air or $O_2$] at the cathode. The oxidation reaction takes place in the presence of electrolyte ["can be acidic or alkaline"].
Fuel cell consists of 2 electrodes, electrolyte, supporting matrix and bipolar material.
Entering gases diffuses through the electrolyte to the electrodes where electrochemical reactions takes place. Supporting matrix is used to support the electrolyte and separate between gases at both electrodes of the same cell. Bipolar material is used to connect between different cells so it must be of high conductivity at the same time must be impermeable as it separates between gases of anode and adjacent gases of cathode of the next cell.

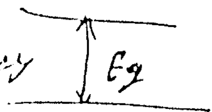
/ Types /

* photovoltaic cells:-
are type of ~~[illegible]~~ ~~do~~ solar devices designed to benefit from solar energy. They are semiconductor devices that converts solar energy into direct current electricty.
operation :- ~~when photons fo~~
Incident photons on the semiconductor material promotes electrons from valency band to conduction band leaving the holes ~~[illegible]~~ The movement of electrons produces an electric current

* Three T's of combustion
are factors affecting the effeciency of combustion process in conventional power plants. [must be optimized]

1- Temperature, sufficient combustion temp. must be reached to allow ignition of fuel [S I T] Spontaneous ignition temp.
2- Time :- adequate fuel residence time must be achieved to allow for complete combustion.
3- Turbulence :- adequate mixing of fuel and air

* Energy gap :-
The difference between valency band and conduction band of the semiconductor.
It is also considered the min. energy that photon must supply to promote an electron to the conduction band to produce electricty.




* cell over potential
is irreversible losses that causes the cell potential to decrease below its eqm. potential.
It occurs at cathode and anode due to activation & conc. overpotentials. In addition to ohmic over potential (IR) due to ~~losses~~ resistances in electrolyte & electrode.
conc. over pot. ~~is~~ maybe due to slow diff. in gasphase in the electrode pores or dissolution of reactants in the electrolyte.
activ. over potential is observed when the rate of electrochemical reaction at an electrode surface is associated with sluggish electrode kinetics.

$$V = E - |\eta_{cath}| - |\eta_{anode}| - IR$$

Advantages of fuel cells

[1] Higher energy conv. efficiency than traditional ~~fee~~ power plants.

~~This is~~ because they aren't limited by Carnot cycle efficiency.

$\eta_{thermal\ fuel\ cells} = \frac{-\Delta G}{-\Delta H}$

In most cases, $\Delta G$ theoretically is larger than $\Delta H$ thus the theoretical efficiency may exceed 100% depending on operating temp. & press. conditions.

[2] Lower pollution rates

Due to ~~low~~ relatively lower operating temp., produced pollution is much lower. Also due to the absence of contact between $O_2$ & $N_2$, $NO_x$ isn't produced

[3] Noiseless

due to the absence of mechanical rotating machineries as turbines and compressors.

[4] Modular structure.

In traditional power plants, we don't have flexibility ~~to~~ double or ↑ prod. capacity.
Fuel cells have much higher flexibility in changing capacity by varying number of cells.

Disadvantages

- high cost which is mainly due to expensive materials of electrodes and other cell components.
- production of DC current
  - can't be transformed
  - need to be inverted first

# Différence between Fuel cell & dry cell

- Both are galvinic cells

in dry cell, energy is stored and used when required in a batch wise operation. The reactants are used till they are consumed.
- Recharging can be done by reversing reactions, which involves adding energy to the battery from an external source.

Fuel cell is an energy conversion device, where energy consumption process is continuous and reactants are continously added.

## Reforming processes

Some fuels can't be used directly since their electrochemical oxidation is very low ~~...~~ [e.g. $CH_4$]. They can be converted to other form as $H_2$ which is used as fuel for the cell. Or the anode of the cell can act as a catalyst for the reforming reaction in addition to its nature as electrode.

- $CH_4$ & CO can be converted to $H_2$ through Reforming processes and water-gas shift reaction.

## Fuel cell structure:-

- Electrodes, electrolyte, matrix, bipolar

- Electrolyte not only transports dissolved ~~...~~ reactants to the electrode, but it also conducts ionic charge between the electrodes and thereby completes the cell circuit.
- Matrix:- Inert material to support the electrolyte within it. At the same it shall not interfer with electrode reactions. It also separates between gases at anode and those at cathode.

be very thin porous

IR drop between electrodes

- Bipolar material:- It is used to connect between different cells

r. gas is allowed to pass through its graves at very high speed so it must be of high machinability

- PEFC :-

Electrolyte is an ion exchange membrane [fluorinated sulfonic acid polymer] which is an excellent proton conductor [free sulphonic acid groups] [in aq. state only]. water management in the membrane is critical for effecient performance. The fuel cell must operate under conditions where the by-product water doesn't evaporate faster than it is produced because the membrane must be hydrated. This can be done by controlling entering air moisture content.

★ AFC

- We work at temp. till 205°C, press. ↑ > atm. press. To prevent water from evaporating.
- $CO_2$ must be removed, also CO
- Can't be used on large scale
- If asbestos is dried, $H_2$ & $O_2$ will come in contact and explosion may occur.

★ PAFC     100% $H_3PO_4$

- no need for humidity control
  why high temp. 200°C?
  - To ↑ $H_3PO_4$ conductivity since it is lower than $H_2SO_4$
  - lower poisoning effect of CO [no need for complete purification before the cell]
- $H_3PO_4$ is of higher relative stability than other acids so the cell can operate at high temp.

Prop. of bipolar

1) high electrical conductivity

2) of high corrosion resistance [Vulcan or Flameon] [since acid & alkaline solutions]

3) For mobile source usage it must be of low density

4) ~~good~~ highly machined

5) The present groves provide more uniform gas distribution to the electrodes & also mechanicaly support the porous electrode. They are used as gas barrier to separate the fuel & oxidant stream in adjacent cells.

The most common ~~one~~ is graphite but its main drawback is its high density. [ability to use Al??]

* Why with HCs we can't use alkaline electrolytes?
[e.g. methanol + KOH]

Because produced $CO_2$ will react with KOH giving $K_2CO_3$

1) $K_2CO_3$ conductivity is lower than "KOH" so cell resistance ↑

2) $K_2CO_3$ is of lower solubility so it will precipitate blocking the pores

~~Ex~~ In alkaline fuel cells, we must remove all present $CO_2$ from air, If air is used as an oxidant.

So It's better to use phosphoric acid as electrolyte.

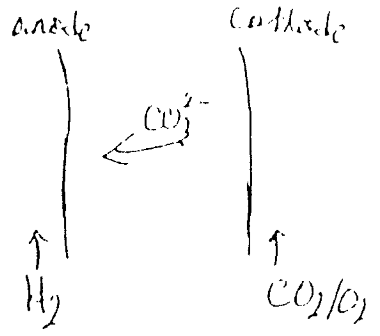
* Ethanol is used instead of methanol since it isn't toxic

* SOFC must be operated at about 1000°C because the transport rate of oxygen ions in the solid oxide electrolyte is adequate for practical applications only at such high tempratures.

* low temp. fuel cells require electrocatalysts to achieve practical reaction rates at the anode and cathode. Electrocatalyst ↑ $i_o$
[controlled amount of Pt]

* "CO" poisons the anode electrocatalyst in low temp. fuel cells, but it serves as a potential source of $H_2$ in high temp. fuel cells

MCFC




cathode

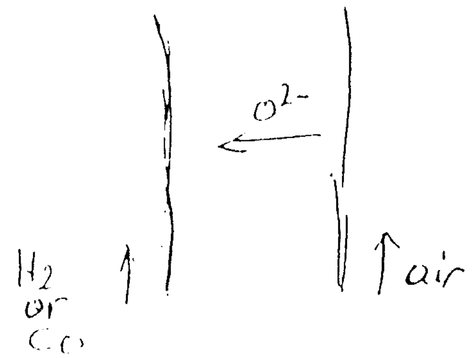
$2e^- + CO_2 + \frac{1}{2}O_2 \rightarrow CO_3^{2-}$

anode

$CO_3^{2-} + H_2 \rightarrow H_2O + CO_2 + 2e^-$

$CO + CO_3^{2-} \rightarrow 2CO_2 + 2e^-$

SOFC




~~cathode~~

anode

$H_2 + O^{2-} \rightarrow H_2O + 2e^-$

~~cathode~~

$CO + O^{2-} \rightarrow CO_2 + 2e^-$

cathode

$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$

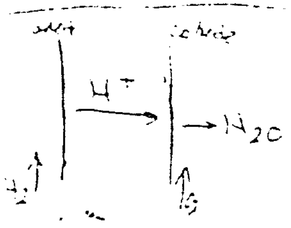
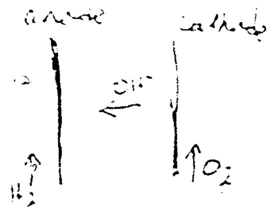
* In MCFC, we can't use 'NiO' as anode, since it will be reduced by $H_2$.

· why recycling $CO_2$?

we have to ↑ $CO_2$ partial press. to shift the rx in reverse dir. so as to maintain $CO_3^{2-}$ conc. level at certain degree. ~~as if~~ ~~anode~~ ~~it can~~ $CO_3^{2-} \rightarrow O^{2-} + CO_2$ as oxide may block the electrode.

$CO_2/O_2$ optimum 2:1

* ~~The~~ In SOFC, CaO or $YO_3$ are added to ↑ conductivity of insulating Zirconia

| PEFC | AFC | PAFC | MCFC | SOFC |
| --- | --- | --- | --- | --- |
| 50–100°C | 100–120°C | 200°C | 650°C | 900–1000°C |
| mobile services | - mobile services<br>- Special applications [Space travel, submarines & electric car] | Stationary systems [power plants] | | |
| carbon black/PTFE [poly tetra fluoroethylene] + Pt catalyst | carbon black/ PTFE + Pt catalyst | carbon black/ PTFE + Pt catalyst | Cathode:- Agglomerated NiO<br>Anode:- Ni | cathode:- $(Sr, La)MnO_3$<br>anode:- $CoZrO_2$ cermet, $CrZrO_2$ |
| ...ation<br>perfluoro sulphonic ... polymer $-SO_3H$ | KOH<br>→ 35–50% [light mobile ...]<br>→ 30–50% [100°C] | 100% $H_3PO_4$ | $(Na, K, Li)_2CO_3$ | Stabilised zirconia<br>$ZrO_2$ + 10% CaO or $Y_2O_3$ |
| ... reed ... | $KTiO_3$ | SiC | Electrolyte tile [50% electrolyte + 50% inert material] | |
| <br>$H_2 \to 2H^+ + 2e^-$   $2H^+ + \frac{1}{2}O_2 + 2e^- \to H_2O$ | <br>$H_2 + 2OH^- \to 2H_2O + 2e^-$ | Same as PEFC | | |

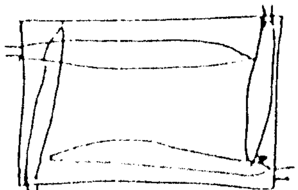
## Coal prop.

lignite :- worst grade of coke
antheracite :- best " " "

As C/H$_2$ ratio ↑, the higher the quality of coke. we ↑ this ratio by removing volatile materials through coking process.

## NO$_x$ level controlling through furnace design

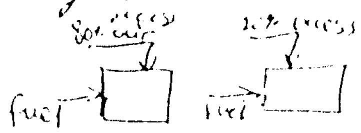
① Arrangement of burners



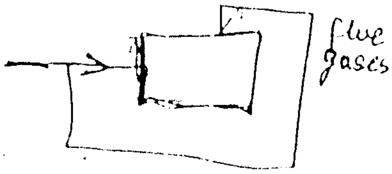
we use tangential firing to spread combustion all over the burner and not to localise them in one area. By doing so we avoid crass rise of temp. in certain regions thus lowering tendency of NOx formation

② two stage combustion

used to divide the amount of rq. excess air on two heaters. by doing so we try to avoid occurence of high temp. & excess air simultaneously to decrease the tendency for NOx formation.

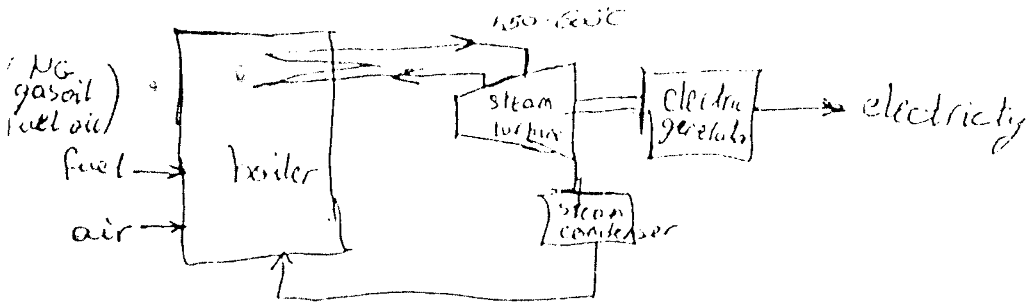



③ flue gas recirculation
used as a dilution mechanism for entering air.



* ~~The boiler is a closed vessel in which water is contained and heated~~

*




* Factors affecting combustion effeciency

1- Enough heat transfer area :- According to the capacity of boiler, based on conv. & radiation sections

- 3 T's of combustion

2 a) Temperature :: suffecient combustion temp. [SIT] spontaneous ignition temp.

3 b) Time :- Adequate fuel residence time to allow for complete combustion

4 c) Turbulence :: adequate mixing of fuel and air

5- proper fuel/air ratio

According to the type of fuel [NG, fuel oil, - ], the amount of excess air required varies.

As excess air ↑, amount of inert $N_2$ increase so heat losses in flue gases will increase thus boiler thermal effeciency ↑.
Although we may reach complete combustion [low CO] but ~~$NO_x$ amount will ↑~~ tendency for $NO_x$ formation ↑.
At low excess air ratio, low tendency for $NO_x$ formation is achieved but "CO" formation increases.

## * Drafting system for air through burners :-

1) Natural draft :- Through difference in densities of inlet cold air and outgoing hot gases.

2) Forced draft :- Air is introduced using compressor [1ry & 2ry air together]

3) suction draft :- fans at the outlet to suck flue gases

## * Diesel engines

Are usually used as stand by generators, of much lower capacity but higher effeciency since they follow auto cycle.

Due to higher comp. ratio & consequently temp → tendency for "CO" & "$NO_x$" is higher

$\eta_{diesel} \to 35\%$

* steam ~~Gas~~ turbines: is a heat engine that takes heat energy from a high temp. & press steam and converts ~~the extracted energy to~~ ~~work~~ it to mechanical energy and rejects unusable waste heat at a lower temp. & press.

* Economiser is used to preheat inlet air used in combustion by produced flue gases.

* Effeciencies

* overall plant effeciency = $\dfrac{\text{Produced electric energy}}{\text{energy stored in used fuel}} \simeq 35\%$

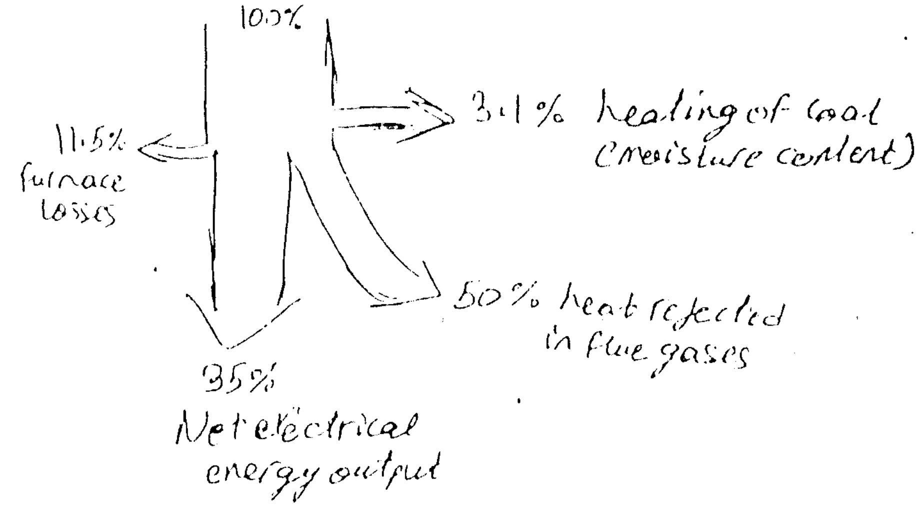
* Boiler eff. = $\dfrac{\text{heat absorbed by steam}}{\text{heat in fuel fired}} \simeq 90\%$

* $\eta_{thermal} = \dfrac{T_2 - T_1}{T_2}$ carnot cycle eff. $\simeq 60\%$

$T_1$ temp. of sink

$T_2$ temp. of hot source

To $\uparrow \eta$, $T_2 \uparrow$ & $T_1 \downarrow$



(7):

1) The overall effeciency of power conversion in photovoltaic cells depends on four different effeciency factors.
The main is "$\eta_a$" which represents the fraction of incident photons on the cells, with energy enough to promote an electron from the valency to conduction band, to total number of photons incident on the cell. This effeciency has a max. of "0.51" as show in fig. The other three effeciency factors are "voltage effeciency", "current collection effeciency" and fill factor. All ~~xxxx~~ has a max. limit of unity. Current collection effeciency depends ~~on~~ "$\eta_{is}$" depends on the rate of neutralization, which is the recombination of part of evolved electrons with +ve holes.
The overall eff. of photovoltaic cells "$\eta_{pv}$" equals to the product of the four effeciency factors. As it can see it must be lower than "0.51" and it doesn't exceed 12% till now.

$$\eta_v = \eta_a \times \eta_{is} \times \text{Voltage eff.} \times \text{Fill factor.}$$

(5)1) Because this energy gap is equivalent to the max. wave length of solar radiation photons. This is necessary to obtain max. effeciency of conversion. As shown this max. is 0.51 and occurs at $Eg = 1.1V$. For an electron to be promoted, the absorbed photon must has energy at least equivalent to the energy gap. Below this energy "$Eg$" absorbed photons doesn't produce any effect. And higher than it $E > Eg$, effeciency decreases because vibrational relaxation occurs in the upper excited state before the charge transfer process take place

Adv. of fuel cells

[1] Higher energy conv. effeciency than trad. power plants

Because they aren't limited by carnot cycle effeciency.

$$\eta_{thermal})_{fuel\ cells} = \frac{-\Delta G}{-\Delta H}$$

In most cases, $\Delta G$ ~~theo~~ is larger than $\Delta H$ thus theoretical effeciency may exceed 100% depending on temp. & press. conditions.

[2] lower pollution rates

Due to relatively lower operating temp., produced pollution is much lower. Also ~~due~~ the absence of contact between $O_2$ & $N_2$, $NO_x$ isn't produced.

[3] Noiseless

due to the absence of mechanical rotating machinery as turbines & compressors

[4] Modular structure

Allows higher flexibility in varying production capacity

Also the plant eff. is const. and doesn't depend on an optimum prod. capacity as trad. plants
(cell written above "plant")

[5] Cogeneration capability

where produced ~~energy~~ beside electrical energy heat energy is

* Thermal effeciency of fuel cell
is the ratio between energy produced from fuel cells represented by ~~ΔG~~ diff. in Gibbs free energy and the calorific value of fuel used (ΔH)

$$\eta = \frac{-\Delta G}{-\Delta H}$$

* calorific value..
is the amount of energy released during the combustion of a unit weight of fuel
units :- Btu/lb , KJ/Kg for solid & liq. fuels
KJ/m³ " gaseous fuels

* Steam turbine.
is a heat engine that takes heat energy from a high temp. & press. steam and converts it to mechanical energy and rejects unusable waste heat at a lower temp. & press.

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$\boxed{4}$ ~~Fuel~~ expensive

The capital inv. req. for a traditional power plant is $500 per 1Kw while for fuel cells it is 10,000 $/Kw. This is due to the expensive materials used in the cell as electrodes, electrolytes, electrocatalysts (pt) & so.

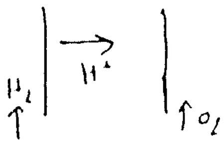
* $CO_3^{2-}$ ions are stable at room temp. but at high temp. as the case in MCFC $CO_3^{2-}$ tends to decompose to oxide ions

$$CO_3^{2-} \longrightarrow CO_2 + O^{2-}$$

formed oxides may block the electrode pores.
So we have to maintain $CO_3^{2-}$ conc. at certain level and this is done by ↑ $CO_2$ partial press. thus shifting decomposition reaction in the reverse direction.

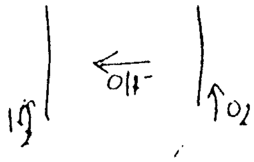
* 1- Carnot cycle effeciency
  2- energy transformations accompanied by energy losses

The overall



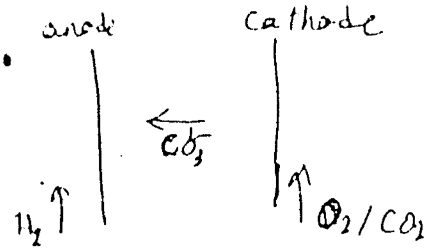

$H_2 \rightarrow 2H^+ + 2e$

$2H^+ + O_2 + 2e^- \rightarrow 2H_2O$




$H_2 + 2OH^- \rightarrow 2H_2O + 2e^-$

$\frac{1}{2}O_2 + H_2O + 2e^- \rightarrow 2OH^-$




$H_2 + CO_3^{2-} \rightarrow H_2O + CO_2 + 2e^-$

$CO + CO_3^{2-} \rightarrow 2CO_2 + 2e^-$

$2e^- + CO_2 + \frac{1}{2}O_2 \rightarrow CO_3^{2-}$


$H_2 + O^{2-} \rightarrow H_2O + 2e^-$

$CO + O^{2-} \rightarrow CO_2 + 2e^-$

$\frac{1}{2}O_2 + 2e^- \rightarrow O^{2-}$

$W = IV = iVA$

$E = -\frac{\Delta G}{nF}$